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6. AUTHOR(S)

J. P. Leburton

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)

University of Illinois at Urbana-Champaign
Coordinated Science Laboratory
1308 West Main Street
Urbana, IL 61801

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13. ABSTRACT *(Maximum 200 words)*

This research was theoretical in nature and focused on quantum processes in nanostructures. Specifically we have investigated coherent transport and diffraction through arrays of nanostructures and proposed a new field effect transistor, called the AntiDot Diffraction Field Effect Transistor **ADDFET**, purposely design to show tunable negative differential resistance and hystereses. **Optic phonon-assisted tunneling** through barriers containing arrays of dots has revealed I-V characteristics characterized by an abrupt front and a broader NDR compared with double barrier resonant tunneling devices. We have proposed a new **mode-locked far-infrared quantum dot laser** tunable by modulation of acoustic phonon scattering, and a novel **quantum dot spectrometer** with multi-spectral capability. We have implemented the "**scattering time engineering**" technique into a comprehensive self-consistent tool for predicting the performances of a new intersubband, optically pumped, mid-infrared (MIR) laser, and developed a self-consistent model for **single electron charging effects** in quantum dots.

14. SUBJECT TERMS

Nanostructures, quantum dots, quantum transport, phonon-assisted processes, far-infrared laser, spectrometer

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Statement of the problem studied.

This research has focused on three areas: 1) Quantum transport through periodic arrays of nanostructures, 2) Scattering time engineering in quantum structures and 3) self-consistent simulation of single-electron charging effects in artificial atoms.

This research has resulted in 18 publications and 9 presentations at symposia and conferences. In addition we have co-organized the International Conference on "Quantum Devices and Circuits" in Alexandria, Egypt, June 4-7, 1996 with K. Ismail and S. Bandyopadhyay, and organized the "9th International Conference on Superlattices, Microstructures and Microdevices" (ICSMM-9) in Liege, Belgium, July 14-19, 1996, both supported by the European Research Office (ERO) of the US Army.

Summary of the most important results.

1. **Quantum Transport through Periodic Arrays of Nanostructures**

We have developed a new transport concept to control current characteristics and dissipation in arrays of nanostructures. Tightly periodic arrays of quantum boxes or bars are used to produce diffraction of incident electrons perpendicular to the plane of an antidot array. This geometry bears some analogy with single barrier tunneling, and is exactly solvable if the quantum antidots are approximated by repulsive delta-barriers. In contrast to conventional quasi-one-dimensional (1D) tunneling which conserves the component of the electron wavevectors transverse to the current, electron diffraction occurs through multiple channel characterized by transverse components of the wavevectors differing by the reciprocal lattice vector of the periodic array. For 1D array of 2D delta-potentials, highly non-linear and robust characteristics in the vicinity of the Fermi energy when a new channel opens up are predicted. Two lines of 1D arrays reveals rich resonant structures.

We have proposed a novel three-terminal negative differential resistance (NDR) device which combines the structure of conventional field-effect transistors (FET) and a periodic array of quantum antidots embedded in the 2D channel of the FET, and perpendicular to the source-drain current direction. We have shown that the novel AntiDot Diffraction Field Effect Transistor (ADDFET) exhibits tunable NDR and hysteresis which could persists up to nitrogen temperature. The operation of this ADDFET is not restricted to III-V compounds but could also be envision with silicon or other semiconducting materials.

We have also investigated quantum transport through a tunneling barrier containing arrays of dots thereby achieving transverse periodic modulation of the electronic properties of the barrier with two-dimensional minibands and minigaps. Our analysis based on a Breit-Wigner-like formula and taking into account both elastic and phonon-assisted tunneling shows that the I-V characteristics are characterized by an abrupt front and a broader NDR compared with "conventional" resonant tunneling devices; the phonon peak follows the same behavior. Experiments on tunneling through non-periodic ensemble of quantum dots by Sakaki's group

(Nahiro et al, Appl. Phys. Lett. 70, 105 (1997)) also show a sharp current onset similar to our results.

Our theory of phonon-assisted quantum transport in a linear chain of coupled quantum boxes predicting current antiresonances due to Bragg reflection of acoustic phonon in the hopping conduction regime (Yu Lyanda-Geller and J.P. Leburton, Phys.Rev B52, 2779, (1995)), has recently received two independent experimental confirmations (A. Nogaret et al. Proc. MSS-8, Santa-Barbara, July 1997, and L. Canali et al. Phys. Rev. Lett.76, 3618 (1996)). We have extended our theory to the existence of oscillations in the magnetic field positions of Stark-Cyclotron Resonances in confined superlattices, and demonstrated the univocal influence of acoustic phonon on these oscillations which can be used as a powerful phonon spectroscopic tool in confined superlattices.

Mode-locked far-infrared quantum dot laser tunable by modulation of acoustic phonon scattering

Our work of conductance oscillations induced by acoustic lattice vibrations in linear chains of three-dimensionally confined quantum nanostructures or quantum boxes suggests the possibility of exploiting this new effect for modulating the electron scattering mechanisms and controlling non-radiative processes between electron states in superlattice cells. We have proposed a new far-infrared laser with gain and emission frequency modulated by an external voltage which leads to the possibility of mode-locked lasing. This tunable device is based on carrier injection into coupled quantum dot structures with localized electron states for which current oscillates due to interference of acoustic phonon-assisted transitions. The population inversion is achieved by engineering the dot coupling and the collector tunnel barrier characterized by scattering times in the range of the acoustic phonon scattering time. Several quantum dot configurations with coupled quantum dot structures in cascades or superlattices have been proposed. Estimates of the optical gain show that at low temperatures, lasing is feasible below the optical phonon frequency.

The quantum dot spectrometer

In our investigation of transport in arrays of quantum dots, we have proposed a new photodetector scheme capable of multi-spectral channel operation. This novel quantum dot spectrometer makes use of the ability of a quantum dot plane to capture an optical spectrum, and of a resonant tunneling structure to perform spectrally sensitive read-out. We have designed a particular structure made of the InAs-GaAs-AlGaAs system and have simulated realistically the electronic properties for predicting the optical channel capabilities. The structure is currently optimized for experimental demonstration of the device performances.

2. Scattering Time Engineering in Quantum Structures.

We have implemented the "scattering time engineering" technique into a comprehensive self-consistent tool for predicting the performances of a new intersubband, optically pumped, mid-infrared (MIR) laser proposed by our group in collaboration with a French group at the University of Paris, last year. The technique which features confined and interface optic-phonon modes with screening, has been used as a CAD tool for the design of the first AlGaAs/GaAs asymmetric coupled quantum well structure which has demonstrated MIR stimulated emission when pumped with a free electron laser. Recently, the unipolar laser with MIR emission at 15.5 microns has also been demonstrated (O. Gauthier-Lafaye et al, Appl. Phys. Lett. 71, 3619 (1997)).

In the context of "scattering time engineering" we have generalized our phonon model to arbitrary number of coupled quantum wells by using a modified image-charge ansatz, and derived the dispersion of the different phonon modes as well as the corresponding Froehlich hamiltonians. We have shown that owing to the preservation of the phonon and electron wavefunction coherence in the whole QW structure, the new model provides significant differences in the inter- and intrasubband scattering rates compared to the simplistic model assuming independent quantum wells for the phonon dispersion.

3. Self-Consistent Simulation of Single-Electron Charging Effects in Artifical Atoms.

We have also investigated the influence of electron-electron interaction on the electronic properties of quantum dots in a regime where the energy level separation is comparable to or larger than the Coulomb charging energy at low temperature ($e^2/2C >> kT$). A self-consistent three-dimensional (3D) solution of Schroedinger and Poisson equation within the local density approximation is implemented to study the formation of shell structure in highly symmetric quantum dots which is in good agreement with recent experimental results (Tarucha et al., PRL 77, 3613 (1996)). We also have specifically demonstrated the "bunching" of the self-consistent electrostatic potential profile during the charging of the dot corresponding to the filling of a shell. Our analysis has also been able to investigate fine physical details such as anomalously large addition energies at N=10 and N=16 which are due to lifting of degeneracies in the third and fourth shells caused by anharmonicity in the potential. For asymmetric quantum dots, we show that the shell structure disappears, and novel features due to electron-electron interaction lead to the accidental formation of an isolated electron shell called 'Coulomb degeneracy' in the energy spectrum--a merging of two energy levels caused by electron repulsion during the charging of the dot which has its analogy in atomic physics.

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